NUCLEAR ENERGY RESEARCH INITIATIVE

Evaluation of Integral Pressurizers for Generation IV PWR Concepts

Primary Investigator: David K. Felde, Oak Ridge National Laboratory

Collaborators: Westinghouse Electric Company

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Integral pressurizers are a key design feature of several proposed pressurized water reactor (PWR) designs included in the Generation IV reactor concepts based on light water reactor (LWR) technology. These Integrated Primary System Reactor (IPSR) concepts are characterized by the inclusion of the entire primary system within a single pressure vessel, including the steam generators and pressurizer. For higher power output, forced circulation is required and designs include internal pumps, although relatively large natural-to-forced circulation flow ratios remain as favorable operating characteristics. As in conventional PWRs, the pressurizer and its interaction with the primary system are important factors in the dynamic control and stability of the reactor during both normal and off-normal conditions.

This project will develop the tools and methods needed to evaluate and characterize the functionality of integral pressurizer designs for new Generation IV reactor concepts. As part of this process, it is the intent to map the performance of integral pressurizers as a function of their design parameters (e.g., gas content, vapor volume, interface with the primary system). Based on the detailed analysis of pressurizer performance, the work will aim to propose pressurizer design solutions that will allow the reactor system to be simplified or withstand more severe accident scenarios.

The integral reactors are expected to have significant multi-dimensional effects because the entire primary circuit is accommodated within the reactor vessel. Analyses will be performed using a 3-D system thermal hydraulic code (RELAP5-3D) to characterize the inflow/outflow surge rates and the operating envelope required for the pressurizer of a generic integral reactor. As part of this process, safety objectives will be defined and incorporated into the models and applicable bounding conditions. Selection will be made of initiating events leading to the highest degree of reactor over-pressurization or de-pressurization. In parallel, characteristics of the supporting systems (e.g., spray, heaters) will be studied and operating regimes defined. The functional design requirements determined in this phase of the study will be used as input to more detailed analysis of specific integral pressurizer characteristics, as described below.

For each pressurizer type (e.g. steam, steam-gas), the design details that allow it to meet the functional requirements will be identified. The major issues affecting the design of an internal pressurizer for integral reactors are related to the behavior of the interface between the primary circuit and the pressurizer. For a steam pressurizer, the interface dictates the thermal stratification and thereby the separation of the steam phase from the generally cooler primary circuit flow. The steam-gas pressurizer relies on the addition of inert gas to the steam phase to reach the operating pressure conditions. The interface has to be designed properly to avoid large gas concentrations in the primary coolant. In order to examine the thermal and gas transport characteristics of the interface and to characterize the response of the pressurizer to system pressure changes, a comprehensive analysis using a Computational Fluid Dynamics (CFD) code will be made.

Complementary models, correlations, or calculational techniques will be applied, as necessary, to the base CFD code structure using the same solution algorithm. The following principal processes, occurring in the pressurizer, will be analyzed in order to evaluate a particular pressurizer design: expansion and associated compression of the gas phase; spray condensation (condensation on falling droplets); internal condensation and water flashing; condensate fall rate; bubble rise rate; diffusion controlled mass transfer on phase boundaries; gas solubility and content in water under different conditions; and so forth.

A small experiment will be undertaken to refine the CFD model and validate the code results. A scaled model of the pressurizer section of an integral reactor will be built. In-surge and out-surge flows will be determined on the basis of expected operational regimes developed previously. Steam and steam-gas combinations will be tested, varying the gas content. Different interface designs for the pressurizer will be investigated in order to minimize the mass diffusion and maximize the impulse transport through the interface.

Having established characteristics of the specific pressurizer types, an investigation will be made of factors that could potentially affect system stability, and in particular, their effect on the natural circulation capabilities of the reactor. For the gas-steam pressurizers in particular, the effects associated with the non-condensable gas content and its compressibility will be addressed. With information from the CFD studies, an effort will be made to evaluate the circulation stability of a generic natural circulation system typical of the integral PWR designs. The study will parametrically assess the effect of pressurizer parameters (e.g., gas content, gas volume, interface areas) on natural circulation stability.

The systematic approach developed in the previous phases of the study will be applied to a down-selected reactor/pressurizer design. Models and tools developed for the generic reactor will be applied to the specific design. Transient system code runs will be carried out to analyze the evolution of the same initiating events analyzed for the generic reactor for verification of results and of compliance with the established safety and design criteria. In addition, the stability tests and the analysis of the relationship between pressurizer parameters and natural circulation stability performed for the generic reactor will be repeated for the specific reactor/pressurizer design.

From the results of this study, it will be possible to develop a sound approach to pressurizer selection as a function of reactor characteristics, giving the designer the ability to make detailed design decisions. Critical design details and characteristics will be identified and guidelines for application of the results will be developed and provided in the final report.

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